Reprinted from

WORLD DEVELOPMENT

Published by
WORLD DEVELOPMENT (PUBLISHERS)
Oxford · New York · Paris · Mexico City · Toronto · Braunschwei

World Development Vol. 1 No. 8 August 1973

Atomic energy in Argentina: a case history

JORGE A. SABATO, National Atomic Energy Commission, Buenos Aires*

I. INTRODUCTION

1. In the 1950s, and especially after the first 'Atoms for Peace' Conference in Geneva in 1955, research and development on atomic energy was introduced in several less developed countries. It was hoped that this would be a powerful instrument, not only for their scientific and technical development, but also for their general progress and modernization.

Consequently, Atomic Energy Commissions were organized nearly everywhere—following the model of similar institutions already established in the developed countries—and extensive training and research programmes were put into effect.

2. A major point in those programmes was the installation of nuclear research reactors, with foreign technical and financial help (mainly US through the Eisenhower plan), in different countries: Brazil (1958), Congo (now Zaire) and Yugoslavia (1960), Venezuela, Taiwan, Egypt and Portugal (1961), Thailand, South Korea and Turkey (1962), South Vietnam and Philippines (1963), Colombia, Iran and Indonesia (1964), etc.

International aid was channelled to these programmes in the LDCs from a special UN agency, the International Atomic Energy Agency (IAEA), established in 1957.

3. An evaluation today would show that in the majority of cases the net results of those efforts has been quite below expectation, particularly in relation to research reactors, whose installation it has been suggested was 'one of the big follies of the late 1950s'.[1]

There are, however, a few exceptions, and Argentina is one of them. It is precisely the purpose of this paper to show that its atomic energy policy has produced useful results in its specific field (production of electric power, uses of radiation in medicine, agriculture and industry, 'fall-out' control, etc.) and that at the same time it has had an important impact in the socio-politico-economic development of the nation.

In the analysis of the Argentine case history it is important to recognize two features of a general nature:

(*a*) that the Argentine atomic energy policy has been a 'policy without a bomb'. Nuclear weapons were not an objective—implicitly or explicitly—of such a policy. The 'bomb' was never in the Argentine horizon; and

(*b*) that the atomic development took place in a country submerged in a very deep political crisis (e.g., Argentina has had nine Presidents during the period 1955–72) and with a permanent economic crises.

4. Argentine atomic energy policy also has a direct bearing on other, more general, science policy issues, such as the following:

(*a*) Is it possible to do useful and significant R & D in a less developed country in a state of permanent crisis and with an economy rather weak and dependent? If the answer is yes, what then can be done, how and at what price?

(*b*) When a country is in crisis, political, economic and even administrative troubles and difficulties are by definition the norm rather than the exception. In such circumstances, what is the role of the scientist and the technologist? Is it just to do 'good' science and technology like their colleagues in well-organized countries, and if this is not at all possible, to blame others (politicians, the military, trade union leaders and the like) for those difficulties and consequently to emigrate or vegetate if they are not solved?

Or rather is it to understand that their duty is not only to do good science, but also to help to build up the local frame of reference where R & D can be better performed? If so, how will a scientist be able to deal with such a wide spectrum of rather complex problems which will normally be well outside his field of interest and expertise: viz., frequent changes in the budget, lack of foreign currency, impossible customs regulations, censorship, political persecution, cumbersome administrative procedures, etc.[2]

(*c*) Under such circumstances, what is the best training for scientific and technical personnel, general or specific?—Basic or applied?—Within the country or abroad?

(*d*) If instability is the rule, how can an R & D institution be organized so that it can function properly under permanent troubles?

II. BACKGROUND TO THE BIRTH AND EARLY GROWTH OF THE ARGENTINE ATOMIC ENERGY COMMISSION

5. In Argentina, as in almost every other country where atomic energy has been introduced, the history of such development is strongly linked to the history of its own Atomic Energy Authority—Comisión Nacional de Energía Atómica (CNEA).[3] Unlike steam power, which acted in the Industrial Revolution through the socio-economic forces of the time, but not by means of explicit institutional mechanisms, nuclear energy entered into the now-called Scientific and Technical Revolution

---

* This paper was written while the author was at the Science Policy Research Unit, University of Sussex, as a Research Fellow from the International Development Research Center, Ottawa. The author emphasizes that the views expressed in the paper are his own and should in no manner be construed as reflecting the official position of the Argentine National Atomic Energy Commission.

by means of conscious, explicit and planned efforts. The many complex problems of nuclear fission and the fact that its first application was the development and production of a new weapon, made countries aware that its incorporation into society would be accomplished faster and better if under governmental direction and control.

So it was that Atomic Energy Commissions were founded, organizations of great autonomy and power (reporting in most cases directly to the Head of State), directly responsible for the development, production and utilization of nuclear energy.

France was the first country to establish such an institution, le Commissariat à l'Energie Atomique, in 1945; and other countries soon followed.

6. It was as early as May 1950 that Argentina established its AEC by a decree[4] that defined its specific 'mission': to co-ordinate and promote private and state atomic research; to propose to the Executive Power those measures necessary to protect the country and its population against the effects of radioactivity; to propose those measures needed to ensure the national uses of atomic energy in the different economic activities of the country—medicine, industry, transport, etc. According to the same decree, the CNEA 'would report to the President through the Minister of Technical Affairs'.

The establishment of CNEA at such an early date shows the importance given to atomic energy by the then President of Agentina (Perón) and his Government. A clearer indication, however, is the big support that Perón himself gave to the research work carried out in those days by Ronald Richter and his collaborators. In fact the 'Richter Affair' is an important episode in the history of Argentine atomic policy.

7. Ronald Richter, an Austrian physicist who worked on nuclear fusion under Von Ardenne in Berlin, arrived in Argentina at the end of the Second World War. He went to the National Aeronautical Institute in Cordoba city, to work with a group of European (mostly German) scientists and engineers under Kurt Tank, the well-known aircraft designer. Richter met Perón, told him about the possibilities of fusion and the difficulties of fission and proposed a research programme to produce energy through controlled nuclear fusion. In June 1949, Perón approved the programme and a laboratory, the High Temperatures Pilot Plant, was installed on Huemul Island in the Nahuel Huapi Lake, near San Carlos de Bariloche, a famous winter resort, 1,900 kilometres from Buenos Aires. Richter was designated its director.

To help him to overcome bureaucratic difficulties, in March 1951 Perón delegated 'presidential authority' to Richter on Huemul Island. In March 1951, in a press conference, Perón announced that Richter had been successful in his experiments and that pretty soon Argentina was going to be able to produce atomic energy, using a very common element. Perón did not mention through which process and with what element the energy would be produced, but quite obviously he was referring to fusion and to hydrogen, especially when he promised that 'we will put a sun in every Argentine home'.

The Perón announcement was received with wide scepticism all over the world. It is a fact, however, that both in the USA and in the USSR budgets were hurriedly approved to speed up fusion research work, which until then had been going rather slowly. But in Argentina the consequences for Richter were negative; opposition to him began to develop, even in circles close to Perón, and in a few months it was so strong that in November 1952 the High Temperatures Pilot Plant was closed and Richter relieved of his duties.

The research work on fusion was discontinued and Argentina, from then on, followed the same path—fission—that other nations were following.

8. In October 1955, a few weeks after the revolutionary overthrow of Perón's Government, a new decree[5] reorganized the CNEA administration but did not introduce major changes. In December 1956 another decree law[6] was issued which established an organization which continued until 1970. CNEA's goals were then defined in the following terms:

(*a*) to promote and perform studies of nuclear transmutations and its application to scientific and industrial fields; and

(*b*) to control its applications with regard to public interests and hazards.

This legal instrument was complemented in June 1960 by another decree[7] declaring of 'high national interest' the work pursued at CNEA[8] and establishing that CNEA was a direct agency of the Presidency of the Nation.

9. The following were among other legal measures relevant to CNEA:

(*a*) A decree law of December 1956[9] established that all raw nuclear materials—and uranium in the first place—would be of state property and that its exploration, production, and commercialization would be the direct responsibility of CNEA.

(*b*) A decree of January 1958[10] regulated the uses of radio-isotopes and ionizing radiations, and assigned to CNEA all the powers of control on this matter.

(*c*) A decree of January 1965[11] ordered CNEA to carry on a technico-economical feasibility study for the installation of a nuclear power station to feed electricity into the Great Buenos Aires Litoral grid.

(*d*) A decree of February 1968[12] authorized CNEA to accept the proposal for the installation of a 320MW nuclear power station and to sign the corresponding contract before 1 June 1968. The contract was signed on 31 May 1968 between CNEA and Siemens Aktiengesellschaft of the Federal Republic of Germany. The power station—known now as Atucha after the place of its location—is at present under construction, has a nuclear reactor fueled by natural uranium and pressurized heavy water as moderator and coolant, and will be in commercial operation by October 1973.

III. ARGENTINE ATOMIC ENERGY POLICY: ITS MAIN OBJECTIVES

10. The definition of atomic energy policy has proved to be a rather difficult problem in practically every country. There is, however, a key factor, the one concerning nuclear armaments, that has had the biggest influence regarding policy. If a country takes the decision to manufacture the atomic bomb, then its atomic policy will be dominated by this central objective. A country which decides not to make a bomb has no such overriding objective and as a consequence its atomic energy policy is much more difficult to define.

11. Argentine atomic energy policy has been a 'policy without a bomb', the development and manufacture of nuclear weapons never being one of its explicit or implicit targets, not even during the Perón–Richter period.

11.1. *The foremost objective of Argentine atomic energy policy has been to build up an autonomous decision-making capability.* This has applied across the board from decisions on monitoring and controlling 'fall-out' to accepting or rejecting a nuclear disarmament treaty; from choosing a nuclear power station to exploring and exploiting uranium ores; from controlling the disposal of radioactive wastes in the oceans to deciding about the uses of radiation in food preservation. Argentina's autonomy as a sovereign nation can only be deployed if it has the proper 'know-how' to choose and to decide. Such a capability does not come from the heavens and it cannot be imported from abroad: it must be built up.

11.2. *The second main objective is to build up the necessary scientific technological infrastructure required for the optimum social utilization of nuclear energy.* Nuclear energy is not a 'wonder', but it is an important tool for the development of any nation, provided that its society is properly prepared to incorporate it. Nuclear energy is an element that can be employed usefully if the fabric of the society has the basic ingredients for its digestion. As with other new technology, it is essential for the country to be an active participant in the process of its transfer, and not an idle spectator hoping that 'all's well that ends well'.

11.3. *The third principal aim is to provide a 'demonstration effect', showing that R & D is feasible and can be useful in spite of it being carried out in a country immersed in a long and deep socio-political and economic crisis.* This does not sound like a very specific objective for an atomic energy policy, but as a matter of fact it was nearly always present in Argentina to all the participants in the process. Some decisions were made for the explicit purpose of building up the confidence of the scientific community.

12. These three main objectives of Argentine atomic energy policy were not defined explicitly in the 1950s or even in the early 1960s.

Being a 'policy without a bomb', its definition was very difficult and its implementation cumbersome. There were not even good foreign models to be copied and so it was not surprising that nobody was then able to write a declaration of principles defining the objectives of Argentine atomic energy policy. In fact, as we will see in this paper, those objectives were painfully worked out during the process, being finally the consequence of praxis plus thought, of thought plus praxis, in a recurrent feed-back process.

The policy was built up by trial and error, through failures and successes, until a pattern began to take shape and by the late 1960s a definite policy could be first recognized and finally defined. How this was done will be better understood from an analysis of some of the work performed by CNEA in different areas.

13. Development of human resources

Throughout its history, CNEA gave first priority to the training of scientific and technical personnel. Physicists, chemists, biologists, metallurgists, geologists, mathematicians, physicians, veterinaries, engineers (nuclear, electronic, civil, mining, mechanical), lawyers, economists, etc. were trained; but also lathe operators, milling machine operators, dye makers, glass blowers, carpenters, technicians in chemistry and electronics, microscopists, surveyors, cartographers, etc. received all kinds of special training at CNEA and many of them were sent abroad.

The relevant feature of this programme was that training was not just confined to those areas of specific and immediate interest for atomic energy (such as nuclear engineering, nuclear physics, nuclear biology, uranium metallurgy, radio-isotopes etc.), but it covered a broader spectrum under the assumption that:

(*a*) The trained personnel, if necessary, could eventually be used by the country in fields other than atomic energy. And, in fact, this certainly happened: at present hundreds of scientists, technologists and technicians trained by CNEA are working in universities, industry, other government research institutions, hospitals, etc.

(*b*) It was important to provide the trainees with as wide a background as possible, because atomic energy—or any other modern technology for that matter—is not just a 'package of knowledge' but rather a universe in fast evolution.

How this programme was implemented can be illustrated through two specific cases, those of Metallurgy and Physics.

13.1. *Metallurgy*

It is well known that the development, production and utilization of nuclear energy requires a lot of high-level metallurgical knowledge. Thus, a nuclear reactor is one of the most intricate metallurgical 'universes' to be thought of: metallurgical problems range from the purity of the uranium dioxide used as a fuel to the mechanical properties of the pressure vessel that contains the core; from the many and complex stages of fuel element manufacture to the corrosion resistance of the heat-exchange tubes; from the basic physical properties (density, thermal conductivity, electrical conductivity, etc.) of the different metals, alloys and oxides used in the reactor to the more relevant techniques in foundry, forging, rolling, extrusion, welding, etc. to be used in their manufacture, etc.

CNEA then, like any other atomic energy commission, needed to have metallurgy as one of its scientific-technological branches; and so in 1955 it was decided to create and organize a metallurgy division.

To understand how this was done, it is important to know that, at the time, metallurgy was not taught as a regular subject in any of the Argentine universities, and that neither organized, systematic nor modern metallurgical research was then carried out by any government, university or private research centre or laboratory. In fact, metallurgy was a sort of outcast in the academic world, despite the fact that the electro-mechanical-metallurgical industry already comprised about 25 per cent of all Argentine industry and that this sector was already more important (30 per cent of GNP) than the classic agricultural sector (25 per cent of GNP). CNEA could have decided to ignore this state of affairs and so apply all its efforts to organize a typical nuclear metallurgy laboratory, just the right one for its own specific interests, like the Metallurgy Division at Argonne National Laboratory in the USA, Chalk River in Canada, or Harwell in the UK, etc.

This would have been the 'easy way'; but CNEA chose the 'hard way': it decided that its Metallurgy Division would not only give CNEA all the metallurgical knowledge that it needed in its atomic energy programme (and particularly in the nuclear fuel area) but also that it would help Argentine industry to improve the quality of its production and the efficiency of its processes, while at the same time promoting metallurgy as an academic discipline. Consequently, the CNEA Metallurgy Division was established along the following lines:

(*a*) Its personnel would be trained not specifically in nuclear metallurgy, but in modern general metallurgy, with a solid background in physical metallurgy.

(*b*) Its laboratories and other facilities (library, workshops, pilot plants, etc.) would be installed and organized in such a way that together with their specific work in nuclear metallurgy—mainly the development of fuel elements—they could also tackle other metallurgical problems of interest to industry.

(*c*) It would actively promote academic activities in the field of metallurgy, in close connection with universities and other government and private research centres and laboratories.

Now, after 15 years of work, a review of the activities of the CNEA Metallurgy Division shows the following:

13.1.1. It has solved all the nuclear metallurgy problems identified for it by the CNEA atomic energy programme. In particular, it has developed and manufactured all the fuel elements for the five nuclear research reactors installed by CNEA (see 16.2) and it has developed a prototype fuel element for the Atucha reactor.

13.1.2. Its staff has published more than 250 papers, mainly in well-established international journals, covering a wide metallurgical spectrum: diffusion, recrystallization, heat treatment, corrosion, sintering, solidification, radiation damage, rolling, forging, foundry, fuel element manufacture, alloy theory, point defects, dislocation theory, non-destructive testing, etc.

13.1.3. Through SATI (see 17.3.2) it has solved nearly 500 problems presented by the electro-mechanical-metallurgical industry.

13.1.4. It has helped to create other metallurgical research centres and to incorporate metallurgy as a regular subject in the curriculum of several universities, in Argentina as well as in other Latin American countries (Colombia, Peru, Chile, etc.).

13.1.5. In the development of human resources:

(*a*) Nearly 500 university graduates have received metallurgy training at CNEA, some 130 of them at present working at CNEA, some 280 with industry, and the rest at universities and at other research centres.

(*b*) Two hundred technicians have received metallurgical training; of these 90 at present work at CNEA, 90 are with industry, and the rest are at universities and other centres.

(*c*) One hundred and thirty Argentine metallurgists went to Europe and the USA for post-graduate training and research. All of them returned to Argentina and the brain-drain from this programme has been nil.

(*d*) Thirty Ph.D. theses were prepared at the Metallurgy Division and approved with honours in foreign and Argentine universities.

(*e*) Ninety-five Latin American scientists and technologists received advanced metallurgical training at CNEA and 20 did post-doctoral research work.

13.2. *The case of physics*

It is rather obvious that any atomic energy programme requires many good physicists. The Argentine situation in 1955 was as follows:

(*a*) There were only 30 physicists in all Argentina, and most of these were principally engaged in teaching.

(*b*) Some research work was then carried on only at the CNEA laboratories, at the Astronomical Observatory of Cordoba and at the Institute of Physics of La Plata University.

(*c*) As an academic discipline, physics was then considered at Universities as a kind of Cinderella: there were very scarce resources, very few professors, few laboratories and a rather small number of students.

The situation became worse during the early 1950s due to the harassment and political discrimination suffered by the universities during Peron's régime.

CNEA decided to put into operation an ambitious programme through the establishment of a completely new institution, the Institute of Physics at San Carlos de Bariloche, financed, administered and directed by CNEA, although formally incorporated into the University of Cuyo for the purpose of granting M.Sc. and Ph.D. degrees. The institution was organized following US and European models: full-time staff doing not only teaching but also research; a maximum of 20 students per year living on campus with fellowships given by CNEA; well-equipped laboratories and workshops so that the students would have plenty of opportunity for experimental work; an up-to-date library and, last but not least, a beautiful location by Lake Nahuel Huapi near Bariloche and 2,000 kilometres from Buenos Aires.

Since 1958, when the first 13 students graduated, the Institute at Bariloche (now named after Dr. J. A. Balseiro its founder and first director) has graduated around 180 M.Sc. in physics, of which more than half have obtained a Ph.D. degree; less than 100 at present work for CNEA and the rest are at universities and other research centres. The Institute is the best school of physics in Argentina and it has won a wide international reputation.

13.3. *In summary*

The two cases just analysed show that both in metallurgy and in physics the action of CNEA in the development of human resources has been wide in scope and deep in quality and so it has led to the formation of personnel able to do R & D not only in the specific field of atomic energy but also in many other fields equally important for the scientific and technological development of Argentina.

14. Development of nuclear raw materials

The first explorations for nuclear raw materials took place in 1950. From then on, systematic studies have been carried out to find and to develop resources in uranium, thorium, graphite, zirconium, berylium and heavy water.

The most important results have been obtained in uranium, were reserves equivalent to more than 8,000 tonnes of uranium oxide U_3O_8 have been evaluated. Potential reserves are estimated to be 13,000 tonnes U_3O_8. According to the authoritative *Resources d'uranium* (December 1967) published by the International Atomic Energy Agency and the European Agency for Nuclear Energy, Argentina ranks among the first ten nations in the world in uranium reserves.

With reference to the production of uranium of nuclear purity, Argentina has three plants of rather small capacity but enough to produce the uranium required by the Argentine market. It has been in these plants that the 'yellow cakes' necessary for the manufacture of the 50 tonnes natural uranium of the Atucha's first core has been produced.

It is important to recognize that the technical capability now exists in Argentina to carry out all the tasks, from initial prospecting to the final chemical purification. This knowledge has been of paramount importance for Argentine's autonomy of decision, particularly with regard to the problem of selection of the reactor for the Atucha power station.

15. Development of a nuclear safety capability

In the context of this paper, 'nuclear safety capability' means the capacity that a country has in all matters related to the protection of its population from the dangerous effects of radiation and radio-isotopes. This is, of course, a very relevant mission for any atomic energy commission, and such it has been for CNEA, whose authority for monitoring and control is established by a law that makes compulsory a permit issued by CNEA for the installation of radiation sources and its operation, and also for the importation, production, commercialization and utilization of radio-isotopes. The work of CNEA in this field includes also radiological studies of proposed sites for nuclear reactors, R & D on radioactive waste disposal and on decontamination process, radiotoxicological studies, prevention of critical accidents, etc.

Very closely related to autonomy of decision on nuclear matters are the studies on 'fall-out'. For years CNEA has systematically collected and evaluated all the relevant data obtained not only on samples picked up in (or on) Argentine territory, but also on the radioactive deposits accumulated in the turbine walls of Argentine commercial aircraft during their regular intercontinental flights. In such a way, CNEA kept a constant watch on the fall-out produced by nuclear explosions in different parts of the world. In that way it was possible for Argentina to know about the nature of those explosions, their magnitude and the possible consequences of their fall-out over the territory of the country. This knowledge has proved to be of value in several problems, some of them of an international nature, such as the non-proliferation treaty.

16. Development of a techno-scientific capacity

The way CNEA developed its own techno-scientific capacity—a most fundamental tool for any country willing to have full command of nuclear technology—is illustrated by analysing two concrete cases. Such a capacity is much more than just human resources plus instruments and equipment plus buildings and ancillary resources: all of them are, of course, necessary but not sufficient; they need to be integrated into a coherent whole. And that is what is shown in the following two examples.

16.1. *Nuclear reactors*

In the majority of present LDCs, nuclear research reactors have been manufactured in some DCs (mainly the US) and then installed by foreign companies. This is what happened in all of the Latin American countries that have installed research reactors (Brazil, Venezuela, Colombia, Mexico and Chile) with the exception of Argentina.

In Argentina CNEA took a very important decision in 1957: that its research reactors were not going to be bought abroad and imported and assembled by foreign companies, but rather they were to be manufactured in Argentina and installed by CNEA with the help of Argentine industry. This decision was taken under the assumption that reactors were important not only for training and research in the nuclear field, but also that its construction would be essential for the purpose of developing a scientific and technological capability. It was reasoned that to manufacture and assemble such a complex machine as a nuclear research reactor would be an excellent way to develop the indigenous nuclear engineering capacity Argentina would need to foster its autonomy. The decision acted as an 'ideological cement' to bind together the human and material resources into an integrated scientific-technological capacity. The following are the five research reactors installed in Argentina since 1958:

(*a*) **RA-1**. This was put into operation in January 1958. The design and engineering came from the US, RA-1 being a copy of the Argonaut reactor developed by Argonne National Laboratory. All RA-1 components were manufactured in Argentina, with the exception of the electronic and control equipments. The assembly and commissioning was performed by CNEA personnel.

(*b*) **RA-0**. A critical facility developed to design a new core for the RA-1. Its design, engineering and construction were Argentine. The RA-0 then led to:

(*c*) **RA-1** (*modified*). Core designed at CNEA and radically different from the original RA-1. Corresponding changes in the engineering of the RA-1 were also introduced.

(*d*) **RA-2**. Argentine design, engineering and construction. It was installed to carry on preliminary studies for the:

(*e*) **RA-3**. The biggest nuclear research reactor in Latin America (originally 5MW, now 8MW). It reached criticality in May 1967 and it was dedicated in December 1967. Designed in Argentina, RA-3 has considerable advantages over the conventional swimming pool or tank models, and its engineering—also Argentine—introduced some novel features. All of its components were manufactured in Argentina, including 90 per cent of the electronic and control equipment. RA-3 is used for research—particularly neutron physics and radiation damage—but mainly for the production of radio-isotopes.

Through these five different reactors CNEA developed a nuclear engineering capacity that was of real importance for the decision to build a power reactor at Atucha.

16.2. *Fuel elements*

Just as in 1957 CNEA decided not to import reactors, it also decided not to import the fuel elements for those reactors but to manufacture them in Argentina. And so they were:

(*a*) *For the RA-1*. Flat fuel elements, 'sandwich' type, with the 'meat' enriched U_3O_8 in an Al matrix and the 'covers' aluminium strips. The 20 per cent enriched U_3O_8 was imported from the USA. The design and engineering were also imported from the USA, but some important improvements were introduced during its manufacture in Argentina.[13]

(*b*) *For the RA-0*. Argentine engineering and manufacture. The enriched U_3O_8 was imported from the USA.

(*c*) *For the modified RA-1*. The same as for the RA-0, but the enriched uranium was now imported from the USA as uranium hexafluoride, being transformed into oxide in Argentina.

(*d*) *For the RA-2 and RA-3 reactors*. They both have the same type of fuel elements, of US design but Argentine engineering and manufacture: a uranium-aluminium alloy cladded with aluminium plates. The 90 per cent enriched uranium was imported from the USA as uranium hexafluoride; for the production of the U-Al alloy a completely new process was developed by CNEA, a process that has been patented in Argentina, the USA, Germany and Japan.

With reference to all these fuel elements, not only did CNEA do the R & D, but it also manufactured all of them. Already more than 4,000 units have been made and all have performed without failure. It is also important to point out that technical innovations were introduced in every type of fuel element, proving once again that to use an imported design does not necessarily preclude innovation, provided that the right kind of human resources are properly motivated.

At the same time this technological activity led to the publication of several scientific papers related to basic problems in metallurgy. This provides a good demonstration that a piece of work as specific as fuel element manufacture can be the source not only of applied but also of basic knowledge.

16.3. *In summary*

The two cases that have been analysed—nuclear research reactors and fuel elements—show how CNEA built up expertise on the fields of nuclear engineering and metallurgy, essential for the development of its scientific and technological capability. If nuclear reactors and fuel elements had been imported—as in other less developed countries—it is rather probable that Argentina could not have been able to follow its line of autonomy.

17. Development of a national techno-scientific infrastructure

One of the key elements in CNEA policy has been a clear understanding of the imperative need to link its activities with the rest of the country, mainly to industry and the universities.

17.1. *CNEA links with universities*

Some of the more significant activities have been:

(*a*) The establishment of research and training centres, such as the Centre for Nuclear Medicine (through an agreement with the School of Medicine of the Buenos Aires University), the Institute of Physics 'José A. Balseiro' (with the University of Cuyo), the Centre for Genetics (with the National Institute for Agricultural Research), etc. In every case, CNEA was the founding institution and provided the original human, financial and material resources. All these centres are nowadays very important in Argentina and some have already achieved an international reputation.

(*b*) The organization and support of pre- and post-graduate courses in physics, metallurgy, biology, radiochemistry, geology, etc., at several universities all over the country.

(*c*) The financial support and the technical, scientific and administrative facilities to prepare more than 100 Ph.D. thesis, that further on were examined in different universities.

(*d*) The financial aid given as research grants to university professors and university laboratories.

17.2. *CNEA links with other state institutions*

CNEA has collaborated closely with several other state institutions and state-owned enterprises, and has carried on R & D projects with them and for them. These projects covered a wide range of subjects: nivometric studies for snow-thawing control; studies on fertilizers, fungicides and insecticides; studies on harbours and port navigability; pipelines non-destructive testing; geophysical surveying for oil; behaviour of different refractory materials utilized in blast furnaces; hydrological studies; wheat and corn deinsectization by radiation, etc. The institutions and enterprises with which CNEA collaborated were the State Oil Company (YPF), the Ministry of Public Health, the State Waterworks Service, the Ministry of Agriculture, the Army Research Office, the National Research Council, the Central Electricity Generating Board (Agua y Energía Eléctrica de la Nación), the Institute of Mining and Geology, etc.

17.3. *CNEA links with industry*

For any atomic energy programme to be successful it is important that the technological level of local industry be high. CNEA has therefore helped Argentine industry in several ways.

17.3.1. Development and promotion of the use of new materials and the application of new techniques, processes and equipments, both in industrial manufacture and in production control. Examples include: the development of a new metallographic technique for the non-destructive testing of boiler tubes; a procedure to measure cellophane paper thickness using beta-ray equipment; application of radioisotope techniques to study the waste of steel balls used in mineral grinding, the measurement of liquid levels in industrial tanks, the performance of cement furnaces, etc; the control of electronic instruments manufactured in Argentina and the development of new ones; the use of fracture mechanics techniques to evaluate the probable life of pressure vessels; the development of a new process to transform soft wood into hard wood through polymerization by irradiation; the development of a new furnace for the bright annealing of copper, etc.

An important effort on the part of CNEA has been the training of industrial personnel through preparatory and refresher courses on subjects such as foundry, heat treatment, plastic deformation, modern physical metallurgy, uses of radio-isotopes, etc.

17.3.2. The most systematic action that CNEA took was to link itself with industry through the establishment of SATI (Service of Technical Assistance to Industry) in 1962. SATI was created by CNEA in association with the Chamber of Metallurgical Industries to be a consultant body to Argentine industry in all kinds of metallurgical problems. The purpose was to make available to industry the scientific and technical resources available at the CNEA Metallurgy Division.

SATI was set up to study problems presented by industry, but it was also able to propose R & D projects that could benefit the performance of industry, improving processes already in use or opening new lines of activities. Routine matters such as mechanical testing, chemical analysis, metallographic inspection and the like would not be performed by SATI on the assumption that there were already in Argentina other laboratories, private and state, that could perform those activities quite efficiently. SATI would also act as a sort of 'clearing house' for information, advising customers where their problems could be better solved and by whom.

A rather brief summary of the main activities carried on by SATI during the last 10 years follows:

(*a*) It has studied nearly 500 problems presented to it by industry. Some of the problems were as trivial as the study of impurity distribution in aluminium castings; others were as ambitious as the complete development of a new Cu-Zr alloy for welding electrodes.

Some of the problems dealt with by SATI were quite divorced from nuclear metallurgy—such as the development of a new process to manufacture tungsten-silver electrodes. Other problems such as the analysis of cracks in pressure vessels used by the petro-chemical industry were directly related to nuclear reactor components.

(*b*) It has developed new products and processes, such as a new type of refractory material to be used in aluminium melting; a new process for the manufacture of aluminium evaporators for refrigerators; a new type of protective atmosphere for bright annealing of copper and its alloys; a new method to produce tough-pitch copper in small melting furnaces; a new type of 'ball-pen', etc.

(*c*) It organized a number of seminars, conferences, lectures, round tables, etc. on specific metallurgical topics of industrial interest.

(*d*) It organized (once or twice a year) special courses for the training of industrial personnel, some at introductory level, some at a higher level.

SATI has performed two very important functions for CNEA:

(*a*) It has been (and is) a mechanism for coupling R & D with industry, a sort of window onto reality. SATI has helped to make CNEA scientists aware of the needs of industry and also of its own possibilities and limitations. Thanks to SATI, CNEA has not been an isolated institution.

(*b*) It allowed CNEA to know pretty well the real state of technological development of Argentine industry, and so to evaluate from a very strategic position the actual possibilities of local participation in any big nuclear programme. This knowledge proved to be very valuable when the Atucha nuclear power station contract was discussed.

18. The very real accomplishments of CNEA should not obscure the fact that the Commission has had to face up to some major obstacles which have—at times—seriously undermined its effectiveness. Relatively few of the obstacles were directly political, although the recurrent political and economic crises in the country did have an indirect effect.

The principal difficulties have been bureaucratic and administrative, and are common to almost all less developed countries. They include such factors as rigid limitations on the assignment and employment of current expenditures, excessive red tape, long delays in the decision making process, low salaries, rigid promotion system,[14] etc. All of these petty frustrations produced an atmosphere which was inimical to creative work and produced a feeling of impotence. This sometimes led to the emigration both of professional coaches (scientists and engineers) and other technical personnel. These reactions were not unique to CNEA and permeated throughout Argentine society.

In addition to leading to extensive migration, the various obstacles resulted in another manifestation typical of much indigenous science in less developed countries. Scientists and engineers tried to isolate themselves from the rest of society and wrap themselves in a cocoon of 'good science'. They did not realize that their responsibility was wider in scope and that it included their important contribution to building up the frame of reference where such 'good work' could take place at all. They were, in fact, assuming quite wrongly that Argentina was a country already built and consequently that science and technology could be developed as smoothly as they were in the developed world. They demanded a coherent policy as an essential prerequisite for them to be able to do science, a very demanding request in a society that was not in a condition to define any policy at all. In fact, in those circumstances, a policy cannot be given, it must be built up.

Such naivety made them ask for an order, a security and a continuity that no country in crisis could ever offer. Scientists and technologists were looking for a 'strategy for order', while the only possible one was a 'strategy for chaos' and so like children they claimed for a world of dreams instead of facing the reality as it was and assuming its corresponding responsibilities. For many of them, emigration was the only answer to finding the necessary peace and security to do R & D; but it was also a way of escaping the most fundamental problem facing any intellectual in a less developed country, his own contribution to the eradication of underdevelopment!

These difficulties meant that CNEA did not use its human resources as efficiently as it should, nor were the basic disciplines coupled as efficiently as possible to technology, and the administrative and managerial services were not well organized. All this had a bad influence on some important programmes, namely:

(*a*) the local production of uranium which was several years behind schedule;

(*b*) the construction of the RA-3 research reactor which was finished three years behind schedule;

(*c*) a long delay, and final blow, for the project to build a 40MW power research reactor that would have provided a lot of experience for a bigger and better participation in Atucha;

(*d*) the very sparse work, and of rather poor quality too, in important subjects such as heat transfer, fluid mechanics, system analysis, etc.

It is obvious that the whole set of obstacles, all operating simultaneously and feeding back one to the other, seriously damaged atomic development in Argentina, probably led to a five to eight years' delay in the scheduled programme.

It is more important, however, to realize that obstacles of this kind will not disappear until some other big changes take place in Argentina, but it seems that such a wonder will take quite some years to happen. Meanwhile it is in such a country (the only one we have got!) where R & D must be performed, more and better if underdevelopment is going to be defeated.

IV. THE ATUCHA NUCLEAR POWER STATION

19. In January 1965 and through a Government decree, CNEA was ordered to prepare a Feasibility Report, analysing the possibilities of installing a nuclear power station in the geographical region known as the Great Buenos Aires Litoral, where the demand for electric power was then estimated to increase by 1,300 MW in the period 1966–72. This was the beginning of a process that put a severe test on the degree to which CNEA objectives—as described in III—had been really achieved.

Could autonomy of decision be exercised in all the different stages from feasibility studies to final commissioning of the reactor? Atucha was, in fact, the hour of truth for Argentine atomic policy and for that reason it is worth a careful analysis.

20. The feasibility report

20.1. Even in 1965 the common practice in Argentina was to contract feasibility reports and pre-investment studies with a foreign consulting firm whenever the project was of an advanced nature or one requiring heavy investment and financing from external sources. CNEA decided not to contract the nuclear power station feasibility report commanded by the Executive Power, but rather to prepare it under its own direction and responsibility, and with its own scientific and technical personnel. Private consultants, both foreigners and natives, would be hired for specific problems when necessary. Two main reasons lay behind this decision:

(*a*) to follow a policy consistent with the previous decision not to import nuclear research reactors or fuel elements, a line of 'learning by doing'; and

(*b*) to provide a 'demonstration effect' against the usual practice of hiring foreign consultants for work that could be done perfectly well using indigenous talent.

CNEA was also convinced that the study itself would be of importance even if the Government were eventually to decide not to build a nuclear power station at all, but only so provided that the study was performed by CNEA personnel.

To carry out the work, a special task force of about 15 full-time CNEA members was organized under the direction of an Executive Committee whose members were the CNEA chairman and the managers of the CNEA Energy and Technology branches.

20.2. The study was finished within the time limit given to CNEA (14 months) and the report—nine volumes, two principal ones and seven annexes—was presented exactly on the programmed date. It was a comprehensive document,[15] covering the technical, economic, financial, political, legal, social and health problems inherent in the installation and operation of a nuclear power station, as well as its impact on such matters as the conservation of natural resources, the development of Argentine industry, the possible changes in socio-cultural patterns, etc. Four types of nuclear power station (two with natural uranium reactors and the other two with enriched uranium reactors) at two different power levels (300MW and 500MW) were thoroughly analysed and then compared both among themselves and with two conventional thermal power stations (oil-fired) used as standards of reference or alternative solutions.

The main conclusions of the study were as follows:

(*a*) by 1972 the Great Buenos Aires Litoral power system would be technically ready to incorporate a nuclear power station to its grid;

(*b*) in such a grid, a nuclear power station could be operated during its 25 years of life as efficiently, safely and reliably as any conventional modern thermal station;

(*c*) the installation and operation of the proposed nuclear power station would be competitive, in economic terms, with the conventional thermal station used as a standard;

(*d*) the site chosen for its installation was Atucha, about 100 km north-west of Buenos Aires city, on the west bank of the Paraná de Las Palmas river;

(*e*) from the point of view of the safety of its operation and the health of the neighbouring population the nuclear power station could be operated in conditions equal to other industrial complexes such as petrochemical industries, integrated iron and steel mills, etc.;

(*f*) it could provide an important source of contracts for Argentine industry in the installation and operation of a nuclear power station;

(*g*) a nuclear power station would mean the utilization of uranium resources already discovered in Argentina, and this would make a significant addition of a new fuel to the traditional line of oil, carbon and gas;

(*h*) Argentine scientific and technological development would certainly benefit quite significantly from a project like Atucha, whose effects would extend quite beyond CNEA's own boundaries.

The report ended by advising the Government to install a nuclear power station in Atucha and by requesting authorization for CNEA to call for offers and to negotiate with possible suppliers. The Government approved and so began a new and more complex stage.

21. The negotiations

21.1. To buy or sell a nuclear power station is much more than a simple commercial operation, particularly so when it is the first one and it is imported or exported. This is true for the buyer, and importer, because in so doing it enters into the 'nuclear age' with all its political, technical, and socio-cultural implications and consequences; it is true for the seller, and exporter, because it is the opening of a new market and also a way to increase the political influence upon, and the technical and socio-cultural penetration into, the country that is buying. The main consequence is that governments, not only companies, must be heavily involved in the negotiations of the deal. This explains some of the decisions taken by CNEA prior to any request for offers:

21.1.1 *About the fuel.* The debate on 'natural or enriched uranium' as the most convenient fuel for a nuclear power station has been going on for years everywhere. The only exceptions are the USA and the USSR where the choice was not very difficult since both countries are producers of enriched uranium. By 1972, the debate was over in almost all the developed countries where the problem has been definitively settled in favour of 'enriched uranium'. France was the last country to switch to 'enriched' after a long battle between the Commissariat à l'Energie Atomique, which favoured 'natural', and Electricité de France, which favoured the other. Canada is now the only country offering to supply natural uranium power stations.

The situation is, however, not settled yet in the less developed countries, where the fear of becoming even more dependent on the developed countries through the supply of enriched fuel makes the choice very difficult, particularly so in those cases where the country has enough uranium ore resources to produce its own natural fuel. If the choice is difficult today it was much more difficult in the mid-sixties, when France was very active in the market (it sold a 600MW natural uranium power station to Spain). The most successful stations then in operation were the natural uranium Calder Hall type built in the UK, and Brazil was in favour of the 'natural' line.

In Argentina there was also a strong group supporting the view that Atucha ought to be 'natural' and, therefore, that only 'natural' offers should be accepted. There was also the opposite group which claimed that the natural uranium reactors were a thing of the past, and that every country would become 'enriched' in a few years. The utilities also preferred the 'enriched' power stations.

The final decision taken by CNEA and supported by the Government, was a very pragmatic one:

natural uranium would not be selected *a priori*, but offers would be accepted in both fuels, enriched and natural, and the choice could then be made after a careful comparison of concrete offers, and not be just a selection *in vacuo*.

CNEA thought that in this way it would induce fierce competition among suppliers (and also countries!) and so it would then get better offers. It was the CNEA position at the time that if it was true that natural uranium had important advantages for Argentina, it was very important to quantify them and the only way to do so was through a comparison among different offers.

21.1.2. *About the power level.* The feasibility report demonstrated that the most convenient power level for Atucha was 500–550MW and that it would have been rational to ask for offers at that power level. However there was at a high Government level a powerful group, backed by the Secretary of State for Energy, completely opposed to any nuclear power station. Only after a hard battle did they accept the idea of a 300MW power station but they would never agree to a 500MW one. Now, a restriction of offers at the 300MW level meant that the French would automatically be out of the running, because the economy of any gas-cooled uranium reactor is very poor below 500MW. CNEA considered that it was important to have the French in the race, so it was finally decided that offers could be presented both at 300MW and at 500MW.

21.1.3. *About the tender.* Once the decisions on fuel and power were taken, it was just impossible to call for a formal tender as it is defined and prescribed by Argentine law. At the same time, a formal tender would restrict flexibility, a condition that CNEA considered to be fundamental for the negotiations. The decision was made then that a 'call for offers' would be made instead of a formal tender.

21.1.4. *About delivery time.* When the Secretary of State for Energy finally accepted the Atucha project it was on condition that the station be in commercial operation not later than July 1972. He argued that by that date a 300MW deficit on the supply side would appear and only for that reason would a thermal station—nuclear or conventional—then be necessary. This meant that the delivery time for the Atucha power station had to be only 48 to 52 months. A very short time indeed.

21.1.5. *About financing.* Another important *a priori* decision was that financing facilities ought to be included in every offer, so that once the final choice was made the financing of the project would be automatically secured. Two main reasons lay behind this decision:

(*a*) CNEA was convinced that the big interest in selling nuclear power stations (the market was then clearly a buyer's market) and the fierce competition among possible suppliers would result in very favourable financing conditions;

(*b*) CNEA was also convinced that the usual sources of international finance, such as the World Bank, the Inter-American Bank and other similar institutions, would not consider a nuclear power station for Argentina to be a high priority project. In the particular case of the World Bank it was suspected at the time that it was not especially inclined to support any big project in Argentina.

21.1.6. *About fuel elements.* It was clear to CNEA that the supply of fuel elements for Atucha and any subsequent power stations would be a key element in any atomic energy programme, not only due to its technological and economic importance (Atucha alone would consume about US$2,500,000 yearly in fuel elements), but especially because it would guarantee a full command of the fuel policy. It was then decided that offers ought to include explicit references to the manufacture of the fuel elements in Argentina and the conditions under which the corresponding technology would be supplied.

21.1.7. *About local participation.* As a matter of policy CNEA was deeply interested in making Atucha the point of departure for a nuclear sector in Argentine industry. To achieve such a purpose CNEA specified that the offers for the Atucha project ought to contemplate a maximum of participation of the local industry, covering not only traditional items such as civil engineering, ancillary services and the like, but also important components of advanced design and technology.

21.2. Once the *a priori* conditions were determined CNEA launched its appeal for offers and at the same time began preliminary negotiations with prospective suppliers and their corresponding Governments. The time limit for the presentation of offers was 31 July 1967, by which date 17 different offers had been received.

The attitude of the Governments of the supplier countries played an important part in the negotiations and for this reason they will be summarized here.

21.2.1. *Negotiations with the French.* The negotiations round began with the French. They were the first because they had shown deep interest in the Atucha project early on, even when the feasibility study was still in its first stages. Likewise, CNEA was also interested in a gas-cooled reactor because this was one of the few possibilities for a natural uranium power station. Therefore negotiations were opened and a French mission visited Argentina and inspected the site at Atucha. This was followed by an Argentine mission (CNEA officers and Argentine industrial entrepreneurs) which visited Chinon and Saint Laurent des Eaux, in France, where nuclear power stations were in operation or under construction. A draft of a provisional letter of intention was then prepared by a French-Argentine team.

These negotiations were suddenly broken off by the French in a most extraordinary and unorthodox way: after having promised to present a provisional offer by a certain date, the French completely failed to produce the offer either at the stated time or later and even failed to notify CNEA that no offer would be prepared.

This was, of course, the end of negotiations with the French.[16]

It is interesting to note, however, that at that time France was negotiating with the US the supply of enriched fuel for the first French atomic submarine. It was said both in Paris and Washington that one of the conditions that the American Government imposed upon the French Government in that deal was that France would not follow up the negotiations with the Argentinians. It is hard to believe that the de Gaulle Government would tolerate such an interference in internal affairs, and it is harder still to imagine the USA being worried with what was happening in Argentina in nuclear matters. This was no more than a rumour but unfortunately no explanation has ever been given to account for such uncommon behaviour in international dealings.

21.2.2. *Negotiations with the British.* CNEA tried first of all to get an offer for a Calder Hall type nuclear power station, but the British refused, because they were no longer selling that type of station. Instead, they offered an Advance Gas Reactor (AGR) type, the new nuclear power station developed by the UK Atomic Energy Authority and which was already under construction for the Central Electricity Generating Board. Apart from the fact that no AGR was then in commercial operation and so no experience of its performance was available, the main problem with the AGR was that it used enriched uranium.

CNEA then asked the British where the enriched fuel for Atucha would come from? The answer was that Argentina could get it from the USA under a lease agreement, a type of tri-lateral agreement which was admitted by American law. CNEA agreed to follow that procedure but only if the UK Government would give a full and written guarantee that it would provide enriched fuel (from any source) if as a result of any problem between Argentina and the USA the fuel supply should become discontinued.

The British negotiators were a bit surprised at this condition but finally accepted it and in due course they informed CNEA that the UK Cabinet had agreed to extend the requested guarantee.

This was an important step forward for CNEA, because it proved that it was possible to get enriched uranium from other sources than the USA. However, the British were far less flexible in other aspects of the negotiation such as local participation, fuel element manufacture, financing and, especially, delivery time. They finally informed CNEA that 48 to 52 months was far too short a period in which to build and put into commercial operation an AGR type power station.

21.2.3. *Negotiations with the Canadians.* CNEA was most interested in the Canadian heavy water natural uranium power station. This was because in addition to using natural uranium it also had the added advantage that its design and engineering made it particularly suitable for high local industry participation.

The use of a calandria and pressure tubes instead of a big pressure vessel makes it possible for a semi-heavy electro-mechanical-metallurgical industry like the Argentine one to have a rather important participation. CNEA in fact opened negotiations with the Canadians with every expectation of arriving at a final deal.

But the deal did not go through, for several reasons. In the first place the Canadians were not willing to accept an important Argentine participation, furthermore they were quite reluctant to accept that the fuel elements could be manufactured in Argentina; they doubted that the delivery time could be accomplished and the financial conditions were not the most favourable. Contrary to what was expected by the Argentinians at the beginning, the negotiations were not smooth; from the CNEA point of view, things went wrong because the Canadians behaved as if they were sure winners, they seemed to think that Argentina had no other choice but to buy 'Canadian'. Consequently they did not show too much initiative and flexibility, particularly when it was more necessary, at the initial stages of the negotiations, and when they finally reacted it was already too late.

21.2.4. *Negotiations with the Americans.* These negotiations were quite curious, because the two main American companies involved—Westinghouse and General Electric—did not show much interest in presenting offers. They were not aggressive as usual, but rather very cautious, behaving as if they were convinced that there was not going to be any nuclear power station at all in Argentina; they seemed to think that at a certain time the Argentine Government would finally call off the game.

In Argentina, some were quite happy with this strange behaviour because they believed that CNEA would be in a better position to take a decision if the 'big brother' pressure were not at all present. Other people, however, did want to have American offers because without them it would not be possible to compare natural uranium *vs.* enriched uranium and so they tried hard to get firm quotations from both GE and Westinghouse. Finally Westinghouse was convinced that CNEA 'meant business' and presented an offer worthy of consideration.

21.2.5. *Negotiations with the Germans.* Two German companies presented offers: AEG offered a boiling water enriched uranium power station (under GE licence) and Siemens, a heavy water (under pressure) natural uranium power station, a new design based on a Westinghouse concept and developed by Siemens. The German Government backed both offers with tremendous interest, showing at all times that it was very keen on selling a nuclear power station, almost certainly because it would be the first one to be exported from Germany.

It is worthy of mention that all the financial negotiations with the German authorities were quite fluid and flexible, much more so than had been the case with other Governments. The Siemens offer was the one finally chosen by CNEA, for reasons to be explained below.

22. Evaluation and choice

22.1. A total of 17 offers were presented to CNEA by the closing date (31 July 1967) and the evaluation began at once. The work was performed by the same team that prepared the feasibility report, under the same Executive Committee, and in consultation with other branches of the Government such as the Secretary of State for Energy, the Ministry of Industry, the National Development Council, the Ministry of Economy, the National Security Council, etc. By December 1967, the study was finished and its conclusions were submitted to the Executive Power, which made the final choice in February 1968. A brief description of how the offers were analysed, every one on its own, and then compared among themselves and also with respect to a conventional thermal power station of similar electric characteristics, will provide another instance of autonomy of decision based upon scientific and technical capability.

The offers were quite complex, and so it was necessary to take into consideration no less than 70 variables for each one. Those variables covered such items as: the type of fuel; the total cost of the station; the total amount of financing; the interest rate; the nature and scope of guarantees; the moderator; the turbine; the buildings; the delivery time; the participation of local industry; the experience of the supplier in the nuclear and in the electric business; the estimated generating cost of the station once in operation at a steady state; the manufacture of fuel elements; the cost of insurance; the problems of heavy equipment transportation; the estimated reliability of the station once in operation; its flexibility to follow the estimated load curve; the participation of Argentine scientists and technicians during design and construction; the safety conditions; the control and inspection by CNEA and other authorities during manufacture and assembly of the components; etc., etc.

A 'comparison matrix' was drawn, with the names of the offerers in the columns and the variables in the rows. Appropriate 'weights' were given to each variable according to a priority ranking established by the Executive Committee.

22.2. It is interesting to analyse some of the main considerations taken into account in assigning 'weights' to the variables, as is shown in the following few examples:

(*a*) *Fuel*. This was taken as the most important variable of all, but not so much as to become the 'decisive' variable. An offer with the right kind of fuel and nothing else, could be 'out-weighed' by one with the wrong kind of fuel but with maximum 'points' in all the other variables. Natural uranium got 100 points and enriched uranium 0 points. However, the fuel offered by the British company got 30 points in spite of being enriched, because CNEA was informed by the UK Government that it would guarantee the fuel supply from other sources besides the US. The US companies offered fuel from only one source (their own country) while the German AEG also offered it only from the US.

(*b*) *Financing*. Financing got very high priority, particularly with respect to the total amount to be financed, not only for the obvious reason of chronic foreign currency shortage in Argentina, but also because CNEA was trying to make sure that once the actual construction started, nothing would stop it; and it is common in Argentina for public works to be stopped half-way through, due to lack of fiscal money. This is another instance of planning ahead, assuming that crisis in Argentina is the norm rather than the exception. Consequently, offers that proposed 100 per cent financing would get the maximum number of points while others would get far less.

(*c*) *Technical data*. Every offer would be thoroughly technically analysed and this would include not only the nuclear, but also the conventional, part of it, particularly the turbine generator. With respect to the 'nuclear island', it was agreed to give more points to the most experienced one, but the problem was not, in 1967, as simple as it could be now. At that time the Calder Hall type had the most world experience in nuclear power generation. They had then produced far more kWh than any other type in the world. The Pressurized Water Reactor (PWR) type was the second best, but only so far as experience in nuclear submarines was concerned. As far as previous experience was concerned the worst offer was that of Siemens, because there was only a 50MW prototype in operation.

(*d*) *Economics*. Here, the usual elements were taken into account, with special care being taken to make the offers as homogeneous as possible for the purpose of comparison. This applied particularly to the fact that the total contract cost could be less important than the final cost when generating costs are estimated and introduced, so that a more expensive buy at the moment of signing the contract could be the cheapest one after running for some years.

(*e*) *Local participation*. A lot of attention was given to this item, a very important and rather difficult one. CNEA did not want a typical 'turnkey' contract for a 'black box' but nor did it want a 'white box', that is, a situation where CNEA itself should be the architect-engineer for the project (simply, CNEA was not in a position to perform such a task). The solution was to get a sort of 'semi-turnkey' contract, corresponding to a semi-open 'black box', or what might be called a 'grey box'. Consequently, points ought to be assigned accordingly to how 'grey' the box offered happened to be.

For each of the remaining main variables a similar ranking operation was performed and 'weights' assigned. Once the matrix was covered by these numbers, a 'quasi-quantitative' selection could be made and a first provisional choice arrived at.

22.3. *The Siemens offer*

22.3.1. The main characteristics of the Siemens offer were as follows:

- Fuel: natural uranium.
- Fuel elements: natural uranium oxide pellets in zircalloy tubes. Very long fuels (more than 6m.), quite thin and altogether a very complex component to manufacture, manipulate and use.
- Moderator and coolant: 300 tonnes of heavy water under pressure.
- Financing: 100 per cent financing, including local costs, at 6 per cent interest, repayment in 25 years, the first instalment to be made 6 months after the station was operating in commercial conditions.
- Local participation: estimated at 35 per cent, including some items of complex technology. The contract offered was not a 100 per cent turnkey contract.
- Power: 320MW
- Contract prize: DM 280 million.
- Moderator cost: US$25.50/pound.

22.3.2. As applied to the Siemens offer the 'ranking procedure' described in 22.1 and 22.2 gave the following results:

It got the maximum points on fuel, financing, local participation and delivery time. On the other hand, it got zero points under 'actual experience of the reactor offered'. Under other items it got medium values. None of the offers based on enriched uranium got enough points to overtake Siemens, which had a clear advantage as a result of its four 'firsts'. The UK offer was technically the best of all, but it could not beat Siemens because the financing offered was only 80 per cent of the total amount, the delivery time was more than 52 months, and the local participation allowed was evaluated as rather low, since it did not include components of real technological importance.

However, the score on many items was quite even between Siemens and the Canadian offer. Fuel was of the same kind in both offers, but the Canadian fuel elements were of simpler design and better tested than those of Siemens. Also the Canadian 'nuclear island' had better engineering and its simplicity made it quite suitable for Argentine industry participation. Far more important, the future of the Canadian type of nuclear power station is obviously brighter than the one offered by Siemens.

For other items (economics of generation, moderator, proposed guarantees, reliability, health physics, etc.) both offers were quite similar. Siemens was better on financing, delivery time and the proposed local participation. But finally it was on another three items where Siemens had the definite advantage:

(*a*) Balance of trade: It was far more convenient for Argentina to buy from Germany, a traditional buyer of Argentine goods, than from Canada, whose trade with Argentina was quite low, both countries in fact being competitors in the world market.

(*b*) A comparison between the relative 'strength' of both companies was quite favourable to Siemens, second only to General Electric (USA) in the world ranking of companies manufacturing and selling heavy electrical equipments. It was also considered important that Siemens had a branch in Argentina, very active in all kind of public works and so with a lot of experience about local conditions.

(*c*) During negotiations, it was notorious that the German Government was supporting Siemens with all its technical and economic might. It was evident that for Germany the deal was far more than a commercial one and that a lot of prestige was involved. From the perspective of its 'strategy for chaos' it was important for CNEA to know that in case of any big problem during the construction of Atucha the German Government would help Siemens in every respect.

23. A balance

It is apparent from what has just been described that the Atucha project was a nodal point in Argentine atomic development. It was then that almost 15 years of hard work to build up a decision capability was to be tested in a very intensive exercise. It was a strenous effort but absolutely worthwhile because it showed to what extent Argentina had full command in a field as new and complex as nuclear energy.

But Atucha was also a turning point. Before it, CNEA followed a rather tortuous path trying to find its way in a very muddled world. Consequently, programmes and plans were quite sketchy and a lot was more implicit than explicit. However, once the Atucha project was chosen, the contract signed and the actual construction begun, CNEA had a very clear path to follow. And it certainly did follow it.

23.1. CNEA was involved in all matters related to the actual construction of Atucha. Its scientific and technical personnel did work on civil engineering, nuclear engineering, metallurgy, neutron physics, health physics, non-destructive testing, electronics, mathematics systems, analysis, fuel elements, etc. CNEA also obtained an important degree of participation for Argentine industry, including the introduction of new technologies such as the welding of stainless steel vessels, the manufacture of special tubes for heat exchangers, etc.

23.2. CNEA prepared a concrete nuclear programme (the so-called *Plan Nuclear Argentino 1967–77*) which, besides other concrete projects, includes two nuclear power stations (600MW each) to be installed before 1980. This explains why from 1968 on, every Development Plan for Argentina adds a new source of energy (nuclear) to the conventional ones (fuel and hydro) and a new fuel (uranium) to oil, gas and carbon.

After Atucha, CNEA could and did define precise and specific objectives. The uncertain times were over and nuclear energy became fully incorporated into the common socio-economic activities of the country.

V. SPIN-OFF

24. So far this paper has described how Argentine atomic energy policy was defined and implemented; it has also shown that the main objectives of that policy have been achieved, particularly the capability for autonomous decisions in all matters related to atomic energy. Throughout this process an important spin-off has been produced and this deserves to be analysed in some detail.

24.1. *Spin-off in the education and academic field*

(*a*) Several scientific and technological disciplines were open to academic activities: nuclear medicine, nuclear biology, nuclear metallurgy, reactor engineering, reactor physics, etc.

(*b*) Physics, metallurgy, geophysics and geochemistry, genetics, electronics, analytical chemistry, etc. were strongly developed and more than a thousand persons at undergraduate and graduate level were trained.

(*c*) New academic institutions were founded (Sociedad Argentina de Metales, Sociedad de Medicina Nuclear, etc.) and other already-existing institutions were supported (Asociación Física Argentina, Asociación Química Argentina, Sociedad Argentina de Biología, Unión Argentina de Matemáticas, etc.).

(*d*) The publication of more than 1,300 scientific papers in well-established international journals helped to improve the quality of the scientific work everywhere in Argentina by setting new and higher standards of excellence.

(*e*) Hundreds of scientists from the USA, Canada, the UK, Western Europe, etc. visited Argentina and important links were established between the Argentine scientific community and the international community. Many Argentinians became members of the 'invisible college'.

24.2. *Spin-off in the industrial field*

(*f*) New techniques, processes and materials were introduced in many different industries.

(*g*) New standards of quality and control were defined and put into operation.

(*h*) The successful participation of local industry in Atucha opened new opportunities not only through a better industrial capacity but also through an important 'prestige' effect that operated in the following way: 'If our industry was able to manufacture such and such a component for a very complex project like Atucha, of course it will be able to do the same for any other project that will obviously be simpler than a nuclear power station.' This kind of argument proved to be quite effective in several large projects where Argentine industry obtained a sizeable participation.

(*i*) As industry became involved with atomic energy, a background for a future Argentine nuclear industry has been built.

(*j*) SATI taught several important lessons about the crucial problems of how to introduce R & D into the industrial sector and how to link the scientific and technological infrastructure with the productive structure.

24.3. *Spin-off in science policy and related matters*

(*k*) The paper has already shown the importance of CNEA to the achievement of the major science policy objectives of technological independence. In addition to this the CNEA programme has demonstrated how important it is to develop an indigenous capability in R & D.

(*l*) It has shown that the choice is not between 'dependence' and 'autarky' as is usually presented in many very hot debates, but rather that 'autonomy' is the most convenient and feasible objective to be achieved. It is not 'imported technology *vs.* native technology' which matters, but an autonomous capability to manage and control all the technology flowing through the economic system.

(*m*) CNEA experience has also been important in producing a sizeable increase in self-reliance and confidence in the indigenous ability to achieve a full command of rather complex technologies.

24.4. Finally, the most important lesson has been the following one:

For scholars in general, and scientists in particular, 'science policy' must necessarily be presented in a well-written document, where everything is logically and consistently organized. It is also thought that such a neat document must precede any action. But reality is, of course, quite different; not only because policy is often not defined in such a way, but when it is so the nice document is immediately ignored or changed, either by the very same people who wrote it or by the next minister in the same Government (the half-life of ministries is usually very low!) or in a new government.

A science policy, a technological policy, an atomic policy, etc., will not come from top to bottom, and so to wait for it to happen will be just 'to wait for Godot'. Those policies must grow from the roots and through the action and work of everybody concerned, primarily the scientists and technologists. CNEA experience is that 'organic growth' is the answer, whereas 'organized growth' is no more than a dream.

APPENDIX

SOME FIGURES ILLUSTRATING THE EVOLUTION AND PRESENT POSITION OF THE NATIONAL ATOMIC ENERGY COMMISSION OF ARGENTINA

1. The total money outlay of CNEA between 1950[17] and December 1972--excluding expenditures connected with the Atucha power station[18]—amounted to US$205 million, distributed as follows:

Personnel	US$61.5 million
Investments	US$71.5 million
Current expenditures	US$72.0 million

2. The budget for 1972 amounted to US$12.8 million, distributed as follows:

Personnel	US$6.5 million
Investments	US$3.4 million
Current expenditures	US$2.9 million

3. By December 1972 CNEA had a total personnel of 2,970, falling into the following categories:

Scientific and technical	920
of which holding professional degrees (Ph.D. or equivalent)	500
Administrative	350
Ancillary	1,700

4. Other figures relating to human resources:

Number of:

CNEA scientists by 1952	5
Persons in receipt of training at CNEA	1,800
Persons in receipt of training abroad	600
Foreign experts that collaborated in the training of personnel	190
Foreign students (mostly Latin American) in receipt of training at CNEA	170

5. The following are the main CNEA installations:

Headquarters in Buenos Aires (Av. del Libertador, 8250):

a five-storey building housing the office of the President of the Board, administrative offices, the main library, the central workshop, and the physics, chemistry and biology laboratories.

Atomic Center Constituyentes (CAC) in the outskirts of Buenos Aires:

comprising metallurgy and nuclear engineering laboratories located in several buildings distributed over an area of 12 acres.

Atomic Center Ezeiza (CAE) a distance of 25 kilometres from downtown Buenos Aires:

a 2,000-acre site comprising an 8MW research reactor, health-physics laboratories, a fuel-reprocessing facility, a pilot plant for industrial irradiation and several laboratories.

Atomic Center Bariloche (CAB) at San Carlos de Bariloche, Rio Negro Province:

comprising laboratories, workshops and living quarters for teaching staff and students. The J.A. Balseiro Institute of Physics is also located at CAB.

Cordoba Factory in the city of Cordoba, 800 kilometres from Buenos Aires:

concentration, refining and purification of uranium ores.

Malargue Factory in the south of Mendoza Province, 1,000 kilometres from Buenos Aires:

production of uranium yellow cake of nuclear purity.

NOTES

1. G. Oldham, *Science, Technology and Development*, Institute of Development Studies, Special Paper No. 2 (University of Sussex, November 1966).

2. J. Sabato, 'Quality *vs.* quantity in scientific research: the special case of developing countries', *Impact of Science in Society*, **20**, 3 (1970).

3. J. Sabato, 'Energía atómica en la Argentina', *Revista Estudios Internacionales*, **2**, 3 (October–December 1968).

4. Decree No. 1093/50 signed by the then President of Argentina, General Perón, and his ministers.

5. Decree No. 384/55 signed by the then Provisional President of Argentina, General Lonardi, and his ministers.

6. Decree-law No. 22498 signed by the then Provisional President of Argentina, General Aramburu, and his ministers.

7. Decree No. 7006/60 signed by the then President of Argentina, Dr. Frondizi, and his ministers.

8. In those days to be declared of 'high national interest' was just another gimmick to get through the bureaucratic net. Unfortunately, the gimmick was so widely used by so many other institutions that finally it lost its original power and is now only another rhetorical ornament.

9. Decree No. 22477 signed by the then Provisional President of Argentina, General Aramburu, and his ministers, and further regulated by decree No. 5423 of May 1957.

10. Decree No. 842/58 signed by the then President of Argentina, General Aramburu, and his ministers.

11. Decree No. 475/65 signed by the then President of Argentina, Dr. Illia, and his ministers.

12. Decree No. 749/68 signed by the then President of Argentina, General Onganía, and his ministers.

13. The changes were introduced in the co-extrusion stage of manufacturing, resulting in an improved final product. This know-how was eventually sold to an important German company.

14. Throughout this period there was a considerable degree of stability in CNEA's top management. There were only three Chairmen of the Board in 18 years, and the present incumbent has been in office for 15 years.

15. In 1967 the Vth National Congress of Engineering presented the *Feasibility Report* with the National Award in Engineering.

16. CNEA never got any explanation for this strange behaviour and so it is rather difficult to find out what really happened.

17. Figures relating to the Richter period are not very well known because a good part of the money came from the so-called 'secret funds' of the Executive Power.

18. The Atucha power station—at a contract price of DM280 million—is not paid for out of the ordinary CNEA budget.